# AGILE R&D UNITS' ORGANIZATION BEYOND SOFTWARE – DEVELOPING AND VALIDATING A MULTI-DIMENSIONAL SCALE IN AN ENGINEERING CONTEXT

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# AGILE R&D UNITS' ORGANIZATION BEYOND SOFTWARE – DEVELOPING AND VALIDATING A MULTI-DIMENSIONAL SCALE IN AN ENGINEERING CONTEXT

ABSTRACT

Previous literature addressed organizations' adaptiveness to ever-changing business environments and investigated the concept of agility. However, extant agility research primarily covers the corporate and project levels and is typically located in the information systems and operations management fields. Relatively little quantitative research in innovation management literature exists, and those studies approached the concept solely from an outcome perspective (i.e., increased adaptiveness) instead of elucidating how organizations should organize themselves to be agile (i.e., a capability perspective). This study addresses these shortcomings and adopts a capability perspective since no empirical studies have examined agile R&D units' organization (ARDO). Drawing on dynamic capabilities theory, we develop a measure of ARDO, conceptualizing it as a second-order construct, consisting of six dimensions: a culture of agile values, customer integration, autonomy, an iterative work method, cross-functional capabilities, and flat hierarchies. We validated the measurement by conducting three studies to ensure content, structural, and nomological validity. We applied structural equation modeling on a sample of 175 R&D managers and cross-validated our findings on different hierarchical levels via a sample of 454 R&D employees. The results confirm the second-order nature of the ARDO measure and provide evidence of its positive relationship with front-end success. We advance scarce quantitative research on agility's neglected capability perspective and contribute to the innovation management field by facilitating further empirical research on agile R&D units' antecedents and outcomes in the context of physical product development.

## MANAGERIAL RELEVANCE STATEMENT

This research provides managers with valuable insights to enhance their R&D units' agility. Managers can use the developed measurement model as an instrument to assess their R&D unit's agility level and to constantly track the progress on the way to an agile organization. Moreover, the validated scale allows managers to benchmark different R&D units. The construct's multiple and distinct dimensions allow R&D managers to specifically assess which of their R&D unit's dimensions (e.g., customer integration) are underdeveloped and initiate corresponding improvements. Our conceptualization also highlights the need for increased empowerment in light of self-determination theory and sensitizes managers to regard it as intrinsic motivation's vital source. Moreover, the study provides empirical evidence regarding ARDO's benefits, such as improved adaptiveness and front-end success, indicating that an agile organization, if implemented successfully, pays off. Hence, the results support such organizational changes since they provide fact-based arguments for ARDO's implementation, thus encouraging managers to reorganize their R&D unit. The ARDO characteristics further serve as a guideline for managers regarding which aspects to consider during the setup of an agilely organized R&D unit and are a valuable basis in this respect.

*Index Terms:*

Agile R&D units, Agility, Dynamic capabilities, Front end of innovation, Scale development

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## I. INTRODUCTION

While software development firms use agile methods widely, today's ever-changing business environment forces even traditional manufacturing companies like John Deere to apply agile methods in their processes [1], [2]. Such success stories also attract academic attention, which resulted in manifold scientific contributions on agility [3], [4].

However, taking a holistic view of extant literature shows that we can approach agility from two distinct perspectives, which to date also impeded agreement on its measurement. On the one hand, an outcome perspective considers agility as increased adaptiveness toward environmental changes [5], [6]. Scales following this perspective (e.g., [6], [7]) are indeed helpful, for example, to demonstrate how increased agility affects performance [7], [8]. On the other hand, following Bouwman *et al.* [9], agility can also mean a specific way of working instead of merely the desired outcome. Consequently, Cooper and Sommer [10] consider "Agile" a management approach (a capability) that facilitates agility, speed, and adaptability (the outcomes). Even though applying this perspective would answer the question of how firms should organize to be agile, such scales are not only more scarce but also mostly one-dimensional [11], [12], with some exceptions [13], [14]. Nevertheless, all scales focus on selected aspects like the methods [15], [16] or autonomy and diversity [13].

However, since extant research suggests that agility is a multi-dimensional concept [13], [17–19], it should also be operationalized that way. Bianchi *et al.* [14] thus suggest overcoming partial views on the concept; they call for developing a comprehensive scale to investigate the relationship among the concept's elements and how they relate to performance. Such a scale might be a valuable tool to gain new insights into the concept and clarify how to structure, what processes and capabilities to possess, and which cultural aspects to consider to become agile.

In line with this, the latest scholarly works elaborate that extant agility research strongly focuses on the firm level, thus often neglecting a micro perspective of the concept [4], [20]. In addition, compared to principal research from information systems and operations management (i.e., "agile manufacturing"), scholarly works linking agility and innovation management are scarce, even though increasing speed and flexibility in product development is a recurring topic in management literature [21–23]. Consequently, extant agility research has overlooked the organizational unit, such as the Research & Development (R&D) unit, as a possible level of analysis.

This oversight is surprising, as the organizational capability to be agile should be particularly relevant for the R&D units of industrial product development since it enables speed and responsiveness in development activities [10]. In incumbent firms, product development is an activity of employees nested in smaller organizational units to generate marketable innovations [24]. Traditional development approaches might be favorable when the market, customer (requirements) and technologies are well-known, early tests with customers are not feasible, or the corporate culture highly relies on bureaucracy. Agile approaches are favorable if the problem at hand is highly complex, mistakes are less critical, and an increased uncertainty during development prevails [1], [10]. This particularly refers to the product development process's early stages, the front end [25]. In this context, increased agility plays a vital role by facilitating market opportunities' exploitation and increased adaptiveness toward changes of any kind [5], [7]. While this also refers to software development, extant research particularly calls for investigating agility's application in physical product development [10], [26]. Consequently, we consider R&D units the ideal setting to investigate organizational units' agile capability and develop a measure to assess such an agile organization.

In summary, we are not aware of any study investigating agile R&D units in large industrial firms, particularly their characteristics, even though it would help elucidate how to organize for agility. In addition, no valid multi-dimensional measure exists to comprehensively assess agility as a capability (instead of as an outcome). Addressing both shortcomings, this paper identifies agilely organized R&D units' characteristics and develops a valid instrument to measure agile R&D units' organization (ARDO). This study's overall research question is therefore: *What are the characteristics of agile R&D units' organization (ARDO), and how can they be measured?*

Our scale development approach's theoretical foundation lies in dynamic capabilities theory [27]. Following Teece *et al.* [28], dynamic capabilities are a necessary antecedent for increasing a firm's overall agility. In addition, the ARDO characteristics contribute to the activities that Teece *et al.* [28] identified as crucial for sensing, seizing, and transforming. Consequently, we argue that ARDO is a dynamic capability because it fosters agility, and we conceptualize it along six dimensions: culture, customer integration, iterative work method, cross-functional capabilities, and flat hierarchies.

A comprehensive scale development approach and three separate studies ensure content, structural, and convergent validity. We follow common measure development and validation processes [29–31] to operationalize and validate the ARDO measure. The empirical analyses include data from 175 R&D managers and 454 R&D employees, enabling us to cross-validate the measurement model on different hierarchical levels. We collected data at a globally operating manufacturing firm, which is ideal for investigating agility in physical product development contrary to previous research's software development focus [3], [26].

Linking insights from innovation management literature, organizational theory, and agility literature, our study's contributions are threefold: First, we add to the debate on how to increase a firm's adaptiveness [32], particularly in the context of physical R&D, and advance dynamic capabilities theory [27] by identifying ARDO and its further operationalization as such a competence.

Second, we offer a validated multi-dimensional measure for ARDO that approaches agility from three new perspectives. ARDO shifts the focus from an overall corporate perspective [3] to individual organizational units within large industrial firms; it detaches agility from its software development focus; and, finally, it adopts a capability perspective. Consequently, our measure complements previous scales that only assess a company's adaptiveness [6], [33] or fail to address agility's multi-dimensionality comprehensively [11], [13], [16]. We thus follow the call of Bianchi *et al.* [14] to develop a more comprehensive and fine-grained agility measure and provide a thorough operationalization of the construct. The derived scale allows to identify agilely organized R&D units and investigate their antecedents and consequences, both for the enterprise and the individual, thus advancing scarce empirical research on organizational agility in the innovation management field [8], [34].

Third, our research contributes to agility and innovation management research by providing deeper insights into the interplay between agility and product development performance, particularly regarding the front end [8], [35]. By showing how to gain increased adaptiveness, which ultimately fosters performance, we follow the call of Marzi *et al.* [22] to elucidate which relevant agility principles can be applied to physical product development and thus contribute insights on antecedents to product development performance [36].

## II. THEORETICAL FRAMEWORK

### *A. Agility – Previous Research and Measurements*

Information systems and operations management are the main agility research fields, which brought forth various notable contributions. Agility's emergence dates back to the publication of the "Agile Manifesto" in 2001 [37], triggered by rapidly changing business environments [1]. A similar phenomenon evolved in operations management. Yusuf *et al.* [17] and Gunasekaran [38] developed the first comprehensive frameworks of "agile manufacturing," which still serve as a basis for research in this field [18]. Several studies consider relevant methods [2], [15] and how to scale them from one to multiple teams ("scaling agile") [39]. The thus aspired agile enterprise can "deal with changes that often arise unexpectedly in business environments via rapid and innovative responses that exploit changes as opportunities to grow and prosper" [33, p. 933]. Other studies investigated organizational agility's enablers, barriers, and consequences [3], [4], also regarding potential negative effects in large-scale settings [40], [41]. For instance, Annosi *et al.* [41] found that Agile can harm learning and innovation due to the constant need to deliver in high-frequencies, urgent tasks' prioritization, less documentation, and loss of knowledge and expertise due to increased cross-functional collaboration.

Contrary to agility's central research streams, scholarly works linking agility and innovation management are relatively scarce and mainly focus on the methods [35], even though some research investigates the combination of agile approaches with manufacturing companies' traditional development process [10], [14]. Notably, also other approaches evolved to organize iterative development processes for increased speed and flexibility, for example, by overlapping tasks or improving information flows [21], [23]. Counteracting extant agility research's strong method focus, Grass *et al.* [42] set out to investigate how sociocultural aspects affect agile software development teams, while Kester *et al.* [5] provide a better understanding of the factors associated with agile decision making.

Concerning scarce quantitative research, prior studies investigated organizational agility's antecedents [34] [8]. Kock and Gemünden [6] quantitatively investigated structural and cultural aspects' roles for innovation portfolio decision-making quality and agility. Studies also linked agility to product development performance [7], [8], [22], [43], [44], however strongly focusing on software development. Moreover, the mentioned studies considered either the corporate level or the project level but neglected agile R&D units as a possible unit of analysis.

Since prior literature thoroughly investigated agility, the concept has been defined and measured in various ways but predominantly from an outcome perspective. Table 1 summarizes studies that discuss agility from this perspective and also provide a thorough definition because a construct's conceptualization strongly determines its measurement [29], [45]. Table 2 shows far fewer studies applying a capability perspective. Both tables elucidate that various disciplines defined and measured agility in different ways and that, surprisingly, research has to date neglected R&D units as a potential unit of analysis.

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Insert Table 1 and 2 here

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Whether in terms of definition or measurement, most studies address a firm's adaptability to environmental changes (e.g., new market situations). Accordingly, agility's outcome perspective could be defined as increased adaptiveness toward threats, changing customer needs, and technologies [5], [6]. While this view is helpful, we can also perceive the concept from a capability perspective. In line with Bouwman *et al.* [9] and Cooper and Sommer [10], agility should also mean a specific way of working, elucidating how to organize to achieve adaptiveness as an outcome. The ARDO construct that we propose applies such a capability perspective and provides a valuable new angle on agility.

Table 1 clarifies that a survey-based, one-dimensional measurement focused on agility's outcome perspective (e.g., [6], [7], [46]) is still the most common measurement, although there are also multi-dimensional ones (e.g., [34], [47]). In this respect, it is notable that various alternative approaches to measure agility evolved in extant literature [48]. For example, Serrador and Pinto [49] measured agility as the planning effort during a project.

Table 2 shows that studies focusing on the capability perspective are scarcer and that quantitative studies applying this perspective, contrary to their conceptual counterparts (e.g., [38], [50]), only focus on one narrow aspect. For example, some scales only evaluate the use of specific agile methods (e.g., [15]) or artifacts [12], [16], [51]. Similarly, Sheffield and Lemétayer [11] measured agility only one-dimensionally as the extent to which the Agile Manifesto's agile values are present in a project team. However, some notable initial efforts exist to measure agility's capability perspective multi-dimensionally. Bianchi *et al.* [14] developed a scale to assess the agile manifesto principles' to cope with uncertainty and the resulting changes via three separate scales for sprints, specification, and feedback. Since the authors investigated the highly relevant topic of how these principles' combination with a Stage-Gate approach relates to software development performance, they did not include other essential agility attributes like autonomy or cross-functional collaboration in their measurement. The same refers to the scales by Recker *et al.* [52]. While validating their software development agility construct (i.e., the outcome), these aspects are considered by Lee and Xia [13] as agile development practices (i.e., the capability). However, the authors neglected agility's key artifacts, such as iterative approaches or a close customer relationship. These dimensions are, however, covered by other one-dimensional or at the most arguable two-dimensional scales [11], [16], [52], [53], which once again shows the mentioned aspect's relevance for agility and further supports our ARDO conceptualization. Consequently, since these scales only focus on narrow aspects, no existing higher-order scale thoroughly addresses all of these dimensions and comprehensively captures agility's capability perspective. In addition, all studies focused on the firm or individual project as the unit of analysis and possessed a strong software development focus.

In sum, the extensive engagement with literature shows that the predominant scales used to assess a company's agility from an outcome perspective might help measure a firm's success. However, no measurement comprehensively assesses agility's capability perspective, even though it would quantitatively elucidate which structures, processes, and culture a company or organizational unit needs to become agile. Since no multi-dimensional scale measures an R&D unit's agility from a capability perspective, we propose the ARDO construct representing an R&D unit's specific way of working.

### *B. ARDO – A Dynamic Capability*

Prior research identified dynamic capabilities and several ARDO dimensions as essential enablers of organizational agility [28], suggesting that ARDO is also such a competence, which we further operationalize. Defined as abilities to develop, enhance, combine, protect or reconfigure a firm's assets, dynamic capabilities are vital for firms to address uncertain business environments [27]. In their conceptual work, Teece *et al.* describe various other aspects of dynamic capabilities' (1) sensing, (2) seizing, and (3) transforming/reconfiguring activities, which are highly relevant to gain organizational agility. Sensing, for example, strongly relies on observing the customers, which is ultimately enabled by integrating them into all the development stages. In addition, sensing requires constantly testing hypotheses on the market, for example, through iterative work methods.

Seizing refers to a proactive implementation and getting the job done [28]. In this respect, Teece *et al.* [28] regard hierarchy as agility's enemy and encourage an organizational architecture that allows the required information to float freely from the bottom to the top. Combining such structures with a high degree of self-organization, autonomy, and cross-divisional collaboration facilitates decentralized decision making, responsiveness, and ultimately organizational agility.

Dynamic capabilities' transforming/pivoting dimension relies on continuous delivery and adjustment of minimal viable products. Agile development's experimental approaches make failing and regrouping commonplace, strengthening the need for a supportive culture. Such a culture supports innovative product development and fosters organizational change and constant adaptation to the environment [28].

Consequently, prior research suggests dynamic capabilities for agility include a supportive culture, customer proximity, iterative development approaches, an organizational structure based on flat hierarchies, autonomy, and cross-functional collaboration. These are essential elements of dynamic capability's sensing, seizing, and transforming activities, all of which support agility. In addition, the recent literature review of Marzi *et al.* [22] on new product development also confirmed a customer-focused approach, spiral development, and cross-functional teams as fundamental principles of a flexible product development approach. Moreover, agility literature characterizes agility as a highly employee-centric concept which relies on diversity, autonomy [13], [17] as well as iterative approaches [10], [12] and an intense customer relationship [53]. Consequently, building on these insights and Teece *et al.*'s [28, p. 26] cognitions maintaining that "[s]trong dynamic capabilities can yield organizational agility," we propose that ARDO is a dynamic capability because it increases a company's agility. We operationalize ARDO with the six dimensions (1) culture, (2) customer integration, (3) autonomy, (4) an iterative work method, (5) cross-functional capabilities, and (6) flat hierarchies. The following investigates the distinct dimensions in greater depth and provides further evidence for our conceptualization from the extant literature.

*Culture* refers to a set of values and norms that organization members share and that define appropriate attitudes and behaviors [54]. In agilely organized R&D units, agile values primarily characterize this cultural system [55]. All unit members are highly committed to their assigned tasks, and the group's focus is solely on the goals set in the current iteration cycle. Moreover, transparency of tasks and the project status (e.g., by daily meetings) is encouraged [10], [55], [56]. Mutual respect, courage [55], [56], an entrepreneurial and change-affine mindset [17], [18], [33], [57], as well as a pronounced failure tolerance owing to agility's trial and error approaches [10] further determine the inherent culture, all of which favor project success [35], [56].

*Customer integration* describes a very pronounced company-customer relationship in which the customer is highly involved in inter-firm activities, resulting in additional value creation for both parties [58]. It sometimes even results in co-created products (e.g., customers joining the development team) and thus increased product development success [59]. Agility is considered a highly customer-centric concept [11], [17], [18], [60], and the customers' satisfaction is agile firms' major objectives [38].

*Autonomy* refers to a "self-directed behavior with general limits set by managerial control" [61, p. 86], which, if granted, ensures required resources' allocation and encourages employees' trial- and error experimentations [62], an essential prerequisite for agility's iterative approaches [10], [35]. Agility's core is to enable faster response to a changing environment [60], which implies that empowered individuals take the necessary corrective measures promptly and often based on mutual decision making [17], [35], [63]. Also, Grass *et al.* [42] and Lee and Xia [13] regard autonomy as an agile software team's vital characteristic, which other literature echoes [11], [35], [39], [64] and which can also be explained in light of self-determination theory. Following Coccia

[65], autonomy plays a vital role in organizations since such empowerment, along with a feeling of competence and relatedness, fosters an individual's intrinsic motivation [66]. Consequently, agility provides intrinsic incentives [66] that foster employees' commitment and might explain agility's increased performance [65].

ARDO's *iterative work method* describes the development process's division into short and incremental sequences, repeated until a final product evolves [10], [67]. Based on the Agile Manifesto in 2001 [37] and to better address changing requirements, iterative planning and execution cycles characterize all agile methods [13], [64]. Every iteration aims to provide a product increment to present to the customer [10], [67]. Iterative approaches allow continuous adjustment of objectives to the previous sprint's newly gained knowledge. Thus, sprint reviews and retrospectives reflect on completed sprints, with the next sprint implementing the derived findings [10], [64], [67].

*Cross-functionality* describes a team composition principle in which employees with different functional backgrounds should fulfill a common organizational objective [68]. It is a highly critical agility dimension to cope with today's business environment [13], [18], [69]. The close collaboration across domains, such as R&D Software, R&D Hardware, and business disciplines, enables firms to achieve objectives such as shorter development cycles and firm success [56]. However, in agile R&D units, the literature's classic understanding of cross-functionality is extended to a special kind of collaboration across the unit members. These members have in-depth expert knowledge of their specific field and a widespread general understanding of related areas. These 'T-shape' and multi-skill characteristics [17], [70] help the team members support and replace one another functionally.

*Flat hierarchies* refer to fewer managerial layers in the company's chain of command [71]. Such structures enable faster decision-making processes [39] and therefore contribute strongly to overall increased agility [17], [72]. Furthermore, flat hierarchies positively influence a firm's success by increasing its performance regarding generating ideas in the product development process's early stages [73]. Thus, a drastically reduced number of hierarchical layers prevails in agilely organized R&D units.

The described ARDO dimensions can also contribute to the sources of technological innovation, both incremental as well as radical by nature. Following Coccia [74], both innovation types can result from the synergy of consequential problems and corresponding problem-solving activities. These problems often result from customers' needs, whose detection agile R&D units' customer focus highly contributes to. To subsequently solve these needs, particularly in the presence of technological turbulence, successful firms need to possess efficient and effective problem-solving competencies [74], which often rely on trial and error approaches [75], for example, facilitated by an iterative work method. In addition, the literature highlights striving for continuous learning and cross-functional cooperation to integrate new knowledge and solve complex problems, which can lead to innovation and ultimately secures a firm's competitive advantage [74], [75].

Composed of the above-stated dimensions, *Agile R&D Units' Organization* is an R&D unit's organizational capability that combines cultural, structural, and process-based resources to increase the unit's adaptiveness to changing environments.

## III. STUDY DESIGN

### *A. Research Setting, Sample, and Data*

To achieve our research objective, we conducted a study at a large industrial firm operating globally in mechanical engineering, generating annual sales revenues of around 6.2 billion euros, and employing 32,000 people in over 80 countries. The firm invests 5.5% of its revenues in R&D,

almost twice the industry average. In 2015, the company had launched a firm-wide initiative to implement agile development in their R&D units, with varying degrees of implementation, since the company operates in various industries and markets. Consequently, the strong innovation orientation combined with the R&D units' heterogeneous agility levels and a diverse portfolio of physical products makes the firm ideal to study agile R&D units in an industrial setting. We surveyed 175 R&D managers via an online questionnaire explicitly focusing on the unit level and the front end, which the focal company clearly separated from the subsequent product development process. The informants possessed job titles such as R&D group/unit leader and had responsibility regarding all front-end activities of their unit. Even though participation was voluntary and we provided no incentives, the response rate was 89%. The R&D managers belonged to ten separate business areas which develop diverse technologies in distinct markets. 9% of the surveyed R&D managers were in their positions for less than one year, 35% between 1 and 3 years, 24% between 4 and 7, 17% between 8 to 12 years, and 15% for more than 12 years. In addition, we surveyed 454 employees nested in the R&D units of the same company as the R&D managers. 18% of the employees were with the company for less than one year, 9% between 1 and 3 years, 26% between 4 and 7, 20% between 8 to 12 years, and 27% for more than 12 years. Before the questionnaire survey, we conducted 12 in-depth interviews with agility experts and R&D managers in the focal company whose units apply agile approaches in their product development processes to better understand the phenomenon of agilely organized R&D units.

*B. Measures*

The qualitative-explorative pre-study's interview data confirmed the six ARDO dimensions derived from extant literature [28] and resulted in a conceptual framework containing the six ARDO dimensions and various first-order codes describing these dimensions in greater detail.

Based on these insights, we generated an initial item pool, for which we tried to keep the item number at a moderate level while fully capturing each dimension's theoretical extent [29], [31], [45]. When developing a new multi-dimensional scale, it is recommended to rely on already established scales for the first-order dimensions [76]. We reviewed extant management, organizational theory, innovation management, and agility literature to find appropriate scales for each dimension. However, the extant scales often failed to capture each dimension's notion thoroughly. We hence had to develop numerous items ourselves following the recommendations of DeVellis [31] and Churchill [29]. All items were measured on a ratio Likert scale [31], [77], with anchors at 1 ("does not apply at all") and 7 ("applies completely"), except for the culture dimension's items, which were anchored from 1 ("not at all") to 7 ("to a large extent"). Since we assume the scale's numerical structure to be isomorphic, each ARDO dimension's extent is reflected by the mean of its items, while ARDO itself is represented by the six dimensions' overall unweighted mean. We avoided using the term agility or names of specific agile practices in the items to avoid halo bias, which also allows applying the measure to R&D units that do not specifically consider themselves as agile but might to some extent display agile organization characteristics. Table 3 in the Appendix provides a complete list of all the items.

The *customer integration* scale is based on the co-development scale by Stock *et al.* [59] and Feng *et al.*'s [78] customer involvement scale. It comprises four items assessing how the customers are involved in the R&D unit's product development process.

The *autonomy* scale has been adapted from the autonomy dimension of Kirkman *et al.*'s [79] team empowerment scale and reflects the extent to which the R&D unit can make its own decisions regarding how tasks should be done. We developed an additional fourth item to capture how strongly the employees are encouraged to make their own decisions since this was an important finding from the interviews.

The qualitative pre-study revealed that agile R&D units' *culture* comprises agile values and failure tolerance. We thus developed five items that measure the extent to which the agile values respect, courage, focus, commitment, and openness [55] are present in the R&D unit. In addition, we also developed two items to capture how the R&D units perceive and deal with failures.

For *iterative work method*, we developed four items that reflect common agile working principles, such as sprints, retrospectives, the frequent presentation of prototypes, and the goals' continuous adjustments to newly gained knowledge.

Even though cross-functionality is well-researched [68] and various established scales exist, they fail to capture the whole notion of *cross-functional capabilities* in agile R&D units. These scales focus only on the employees' diverse functional backgrounds. We therefore developed a four-item scale to more explicitly capture the T-shapedness and mutual support among employees as evolved from the qualitative pre-study.

The literature presents various scales to assess *flat hierarchies* (e.g., [71]), which solely focus on the number of hierarchical layers and do not capture this dimension's whole complexity. Therefore, the scales served as a basis to develop a more comprehensive four-item scale.

### *C. Scale Development Approach and Data Analysis Procedures*

The extant literature provides several well-established scale development approaches [29–31], [80], [81], which, however, can all be broken down in a three-step procedure [77]. First, scholars need to create an initial item pool, as presented in the previous section, and subsequently ensure its content validity. Second, they need to further develop and refine the scale, particularly by showing its structural validity. Finally, they need to ensure the scale's nomological validity. We thus conducted three separate studies following the recommendations of DeVellis [31], Hinkin [30] and Worthington and Whittaker [45], as well as recent scale development approaches in innovation management [76], [82], [83] to ensure the construct's content, structural, as well as nomological validity.

Content validity refers to the extent to which a scale's items capture a theoretical dimension or phenomenon [31]. We took three steps to ensure the construct's content validity [45], [76]. First, the dimensions reflecting ARDO were based on 12 in-depth interviews with practitioners who have long experience regarding agility in R&D. In addition, we comprehensively reviewed extant literature, ensuring the evolved conceptual framework's high practical and theoretical validity. Second, five practitioners and one of the authors discussed the initial item pool in four workshops [45]. An academic focus group consisting of four academics with extensive scale development experience followed each workshop to refine the items. Third, we extensively pre-tested the scale [14], [82] with 15 practitioners from the firm's various hierarchical levels. In addition, follow-up interviews with nine pre-testers helped obtain deeper insights for further improvements [45].

Besides content validity, the construct validation process also includes ensuring the scale's structural validity [30], [80], which refers to a measure's ability to operationalize the theoretical construct it has to capture [80]. Exploratory (EFA) and confirmatory factor analyses (CFA) are regarded as common methods to assess a construct's structural validity [31], [45], [82], [83]. The EFA was performed on the initial 27 items using principal component analysis [31], [45]. The number of observations exceeded the recommendation of 150, providing a sufficient cases-to-item ratio of over 6:1 even if all items are retained after the EFA [30], [31], [45]. We conducted several tests before the EFA, including Bartlett's test of sphericity and the Kaiser-Meyer-Olkin test of sampling adequacy, to determine whether the data were suitable for factor analysis [45], [82], [83].

To further assure the measure's structure, the EFA was followed up by the CFA based on structural equation modeling as recommended by DeVellis [31] and Worthington and Whittaker [45]. In this respect, the use of separate samples is also recommended [30], [82], [83]. Thus, we performed the CFA with a sample of employees nested in the same company's R&D units. This step also validates the ARDO measure on a different hierarchical level since cross-validation is pivotal when validating measures [45], [76]. The employees assessed the same scales as the R&D managers, slightly adapted to their context. The sample size of 454 observations provided a sufficient cases-to-item ratio (21:1) [30], [45], [82]. First, we tested a six-factor model with no further specified relationships between the dimensions, followed by a second-order model, in which all dimensions explicitly loaded on the latent second-order factor ARDO [76], [83].

Finally, the construct's nomological validity was assessed, which shows that a developed measure relates to other constructs as expected [81]. It is ensured by showing a significant relationship between the focal measure and theoretically related constructs [30], [82], or potential outcome variables [83]. To fully ensure the convergent validity, we conducted both assessments. First, we correlated agility's newly introduced capability perspective, namely ARDO, to its related and well-established outcome perspective. Bouwman *et al.* [9] and Cooper and Sommer [10] suggest that we approach agility from both angles. Therefore, even though both perspectives are distinct, we expect ARDO and its dimensions to strongly relate to the outcome agility.

Second, we relate ARDO to an established performance measure in innovation management, namely front-end success. Being successful in the front end means generating and efficiently further processing many high-quality ideas and quickly unlocking their market potential [25], [84], all of which ARDO favors. For instance, the iterative work method allows to immediately test a lot of potential ideas [10], thus also favoring unfeasible project's early detection and termination [85], while the customer focus clarifies in which fields ideas are needed [27], [74]. Moreover, the increased autonomy allows pursuing market opportunities quickly, avoiding potentially delaying management approvals [35], [62]. Consequently, ARDO should relate positively to front-end success.

The nomological validation sample again comprised the R&D managers who also assessed their unit's performance. Three items from Kock and Gemünden [6] captured agility as an R&D unit's ability to react to technical changes, changed customer needs, and market changes ($\alpha = 0.80$). Front-end success was measured with four items ($\alpha = 0.85$) taken from the literature [24], [84], referring to ideas and implementable concept studies' quality and quantity in the early product development phase [84]. We conducted the nomological validation by calculating the correlation pattern between ARDO, its dimensions, agility, and front-end success [31].

## IV. RESULTS AND DISCUSSION

This section presents the results of the construct's content, structural and nomological validity assessment. Three conducted measures ensured the developed construct's content validity. First, the qualitative-explorative pre-study and an extensive literature review assured the construct's high practical and theoretical validity. Second, five workshops with practitioners and academics led to the items' continuous improvement and generated a high-quality item pool [45]. Third, the scale's extensive pre-test with 18 practitioners from the focal firm and nine follow-up interviews showed positive results since it ensured comprehension and each item's appropriate assignment to the proper dimension. In summary, the construct's content validity can thus be assured [45], [76].

The construct's structural validity was assured via EFA and CFA since they represent standard methods to identify underlying latent structures in data [31], [45]. The ex-ante conducted Bartlett's test of sphericity was significant ($\chi2$ (351) = 2135.3; $p < .001$), and the KMO measure was .843, which exceeds the recommendation of .50 by far [45], [86]. The data were therefore appropriate to perform factor analysis and could represent underlying latent dimensions.

The EFA categorized the 27 items into six factors with an Eigenvalue higher than 1.0 and accounted for 62% of the observed variance. In the scale refinement process, seven items had to be removed from the original item pool due to low factor loadings or significant cross-loadings [31], [45]. Thus, we conducted the EFA again on the remaining 20 items. The results confirmed ARDO's six conceptualized dimensions, and all items loaded uniquely on their intended factors [29]. Following DeVellis [31], we calculated Cronbach's alpha ($\alpha$) to further validate the scale and to assess each factor's internal consistency. Cronbach's alpha assumes tau-equivalence (i.e., equal covariance of all items with their common factor), which is not always the case in practice. Therefore, we also calculated McDonald's omega ($\omega$) [31], [87]. All values for Cronbach's alpha and McDonald's omega were above the critical value of .70 [29], [31], [87], [88], suggesting high scale reliability. Table 3 presents the EFA's results.

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Insert Table 3 here

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The CFA for the R&D employee sample presented in Table 4 confirmed ARDO's six-dimensional structure since, following Hu and Bentler [89], the first-order model fit the data quite well: $\chi 2$ (154) = 368.7; $p < .001$; CFI = .958 ; RMSEA = .055; SRMR = .042. This result further suggested the dimensions' uniqueness [29], and the calculation of Cronbach's alpha and McDonald's omega also assured this sample's internal consistency [31]. All the factor loadings were higher than .61 and significant ($p < .001$). In addition, the average variance extracted (AVE) was calculated. All the values were above .54, while the flat hierarchies' value was exactly on the cut-off value of .50. We then also determined each dimension's composite reliability, exceeding the critical value of .70 [31].

Since we conceptualize ARDO as a higher-order construct consisting of six dimensions, we also ran a second-order model analysis. The model also had a very good fit ($\chi 2$ (163) = 413.3; $p < .001$; CFI = .951; RMSEA = .058; SRMR =. 051), with all the dimensions loading strongly and significantly ($p < .001$) on the higher-order ARDO construct. Besides the better fit with the theoretical conceptualization and the high correlations between the first-order dimensions [24], [76], the good model fit also supported the second-order construct's choice.

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Insert Table 4 here

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Prior to the nomological validation, we conducted another CFA of the second-order ARDO measure for the R&D manager sample, also resulting in a good fit ($\chi 2$ (164) = 255.4; $p < .001$; CFI = .935; RMSEA = .056; SRMR =.079). All dimensions' AVE exceeded the cut-off value of .50 by far, while culture was exactly on the threshold. Moreover, CR, Cronbach's alpha, and McDonald's omega of the first order constructs were above .70. Table 4 depicts the CFA's final results. Since a single informant assessed all the scales, we conducted Harman's single-factor test. The model had an extremely poor fit ($\chi 2$ (275) = 1173.2; $p < .001$; CFI = .487; RMSEA = .141; SRMR = .127), suggesting that common method bias did not influence our results' validity.

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Insert Table 4 here

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Regarding the interplay between ARDO, agility's outcome perspective, and front-end success, nomological validity would require that ARDO and its dimensions correlate highly with these constructs [30], [31]. We followed Hornsby *et al.* [82] and interpreted significant correlations lower than .20 as small, those greater than .20 but less than .45 as moderate, and those above .45 as large. All correlations were statistically significant ($p < .01$). Just as expected, the large correlation of .50 indicates that agility's capability perspective (i.e., ARDO) is highly related to its outcome perspective (i.e., increased adaptiveness) but not high enough to imply that they are the same. Regarding the ARDO dimensions, culture showed the highest correlations with agility ($r = .44$, $p < .01$), while all dimensions' correlations were moderately high. Also, as expected, the correlation between ARDO and front-end success was significant and strong ($r = .52$, $p < .01$). Moreover, all ARDO dimensions showed moderately high correlations with front-end success. Overall, these results, summarized in Table 5, support our construct's nomological validity.

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Insert Table 5 here

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In summary, all three critical validity tests in the scale development and validation process were successful [31], [77], thus ensuring the ARDO measurement model's overall validity. First, the construct shows content validity in that the ARDO dimensions are conceptually distinct, and the corresponding items capture the theoretical dimension they are supposed to identify [31]. Second, we empirically validated ARDO's structural validity as a second-order construct with six dimensions and cross-validated it with another sample on a different hierarchical level. Third, we showed that ARDO behaves as expected in its nomological net because it is highly correlated to agility, and individual ARDO dimensions show significant correlations with the concept's outcome perspective and front-end success [31]. Consequently, as all three validation steps showed positive results, our 20-item measurement model can be considered a highly valid scale for measuring ARDO. We discuss the essentially new theoretical and practical contributions in the following section.

## V. CONCLUSION

### *A. Implications for Theory*

This study contributes to agility and innovation management literature, as well as to organizational theory in various ways. First, we provide a validated measurement for ARDO and therefore contribute to a better understanding of the practically relevant phenomenon of agilely organized R&D units. Extending scarce quantitative research on organizational agility in the innovation management literature (e.g., [6], [7]), the measurement model presented in this study serves as a useful basis for identifying such organizational units and enables further empirical research. By including additional relevant agility dimensions in our measurement, we complement the scales of Lee and Xia [13] and Bianchi *et al.* [14], thus following the latter authors' call to develop a more comprehensive and fine-grained survey-based measurement of agility. In doing so, we provide a more thorough conceptualization and operationalization of agility in innovation management. Future studies could use the ARDO measurement to empirically investigate agilely organized R&D units' antecedents or outcomes for both the firm and the individual. In addition, by applying a contingency perspective, boundary conditions could be elucidated. Since the scale refrains from using specific "agility" terms, the model could also assess R&D units that do not explicitly consider themselves agile, allowing an unbiased and broad comparison.

Moreover, ARDO approaches agility in a new context, considers a novel unit of analysis, and provides a new perspective on the concept. Our study detaches agility from the predominant research in the information systems [3] or operations management fields [90] and shifts the focus from an overall corporate perspective [4] to individual, organizational units within large industrial companies. In doing so, we address agility's application in physical products' development instead of in the more prominent context of software development [26]. Primarily, however, in keeping with Bouwman *et al.* [9] and Cooper and Sommer [10], our scale approaches agility from a capability perspective (i.e., how to organize to be agile) instead of from the predominant outcome perspective (i.e., increased adaptiveness). Consequently, our scale addresses how to organize to be agile and assesses how agilely organized an R&D unit actually is. Altogether, our study advances scarce research on organizational agility in innovation management literature [34], [43].

Second, the construct's nomological validation also advances innovation management research by providing deeper insights on the relationship between agility and product development performance. While the agile way of working's (i.e., the capability perspective) positive influence on front-end success has been theorized [35], thorough empirical evidence is missing since extant research has only shown how agility's outcome perspective (i.e., increased adaptiveness) relates to front-end and product development success [7], [8]. Thus, our study provides first empirical evidence on how to thoroughly gain such increased adaptiveness, and it demonstrates ARDO's positive relationship with front-end success, supporting prior conceptual work [35]. Because it holistically considers agility and its relationship to front-end success, our study also complements the findings of Bianchi *et al.* [14], who have already shown how single agile principles to cope with uncertainty relate to performance. In addition, we answer the calls by Marzi *et al.* [22] to provide a better understanding of which relevant agility principles can be applied to physical product development, since the concept has mainly been investigated in a software development context, and how to measure these principles to compare them to traditional approaches, e.g., with respect to performance.

We thus contribute to and engage in the longstanding debate of how to improve product development performance [22], [36]. Our study also advances insights on the sources of technological innovations [74], since it shows the relevant activities of R&D units that contribute to customer needs' identification and the subsequent problem-solving activities, all of which generate both incremental and radical innovations. Thus, our empirical findings complement prior conceptual work [74] by operationalizing the relevant R&D activities and facilitating future analysis of technological innovation's antecedents and showing that ARDO's dimensions indeed positively relate to front-end success [25].

Third, we contribute to organizational theory, specifically to self-determination and dynamic capabilities theory. We join the longstanding debate on how firms can cope with an ever-changing business environment [32]. In this regard, various notions, such as strategic flexibility [91] have evolved to date, and also ARDO can be regarded as a new way of making organizations more adaptive to change, particularly in the context of R&D. Moreover, we advance self-determination and incentives theory [65], [66] by showing that the threefold concept of autonomy, competence and relatedness also applies to agile R&D units' context and that it is a vital element of their organization. By showing ARDO's autonomy dimension's strong correlation with both adaptiveness and front-end performance, we provide additional empirical evidence that the resulting intrinsic motivation is performance-relevant. We also elucidate another factor that increases employees' motivation in R&D and which organizations should consider. In addition, we contribute to dynamic capabilities theory [27] by identifying ARDO as such a competence and further operationalizing it. The measurement scale facilitates future quantitative research and could help identify new antecedents and consequences of dynamic capabilities. Teece *et al.* [28] relate several ARDO dimensions to sensing, seizing, and transforming and, subsequently, increased agility and innovativeness. Our results confirm their assumptions, therefore supporting their conceptual framework with empirical evidence and advancing dynamic capabilities theory.

*B. Managerial Implications*

This study's findings provide managers with valuable insights to enhance their R&D units' agility. ARDO's validated measurement model allows managers to assess their R&D unit's agility level, track progress on the way to becoming an agile organization, and benchmark different R&D units. Based on the construct's multiple dimensions, R&D managers can specifically assess which facet of their R&D unit (e.g., customer integration) is underdeveloped and take corresponding actions for improvement. In addition, our results elucidate relevant R&D activities to foster customer problems' detection and solving and thus to create technological innovations. Our conceptualization also highlights the need for increased empowerment in light of self-determination theory and sensitizes managers to regard it as intrinsic motivation's vital source.

Moreover, our study empirically shows ARDO's benefits, such as improved front-end success, proving that an agile organization pays off. Therefore, the study provides further arguments and support for implementing such organizational changes and encourages managers to reorganize their R&D units. The ARDO dimensions provide an important orientation for managers which aspects to consider when setting up an agilely organized R&D unit.

*C. Limitations and Avenues for Future Research*

Despite our best efforts with the study design, our research is not free of limitations, which offer various avenues for future research. First, even though the focal company operates in various industries and has a highly heterogeneous product portfolio and business units in different countries worldwide, the empirical material stems from a single company. Future research should therefore validate the ARDO construct in other industry and company contexts.

Second, while we cross-validated the measurement model with multiple informants, the nomological validation was based on a single informant. Although we took multiple measures to reduce common method bias, we cannot entirely rule out such effects. Future studies could relate the ARDO construct to other (objective) performance measures using a multi-level research design.

Despite these limitations, the construct developed in this study forms a foundation for future research on agilely organized R&D units and the interplay of agility, organizational theory, and innovation management.

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**TABLE 1. Overview of Studies Discussing Agility from an Outcome Perspective**

| Study | Theoretical Construct (Dimensions) | Definition | Type of Study | Unit of Analysis |
|---|---|---|---|---|
| Cai et al. (2019) [34] | Organizational agility (market capitalizing, operational adjustment agility) | *A firm's ability to address unexpected changes via rapid and innovative responses.* | Quantitative | Firm |
| Clauss et al. (2019) [47] | Strategic agility (strategic sensitivity, leadership unity, resource fluidity) | *Strategic agility is defined as a firm's ability to renew itself continuously and to maintain flexibility without compromising efficiency.* | Quantitative | Firm |
| Conforto et al. (2016) [60] | Agility | *The project team's ability to quickly change the project plan as a response to customer or stakeholders needs, market or technology demands in order to achieve better project and product performance in an innovative and dynamic project environment.* | Quantitative | Project |
| Del Giudice et al. (2021) [92] | Organizational agility | *The dynamic aptitude of an enterprise to operate in an uncertain and complex environment.* | Quantitative | Firm |
| Grass et al. (2020) [42] | Team adaptability | *The capacity of a team to make needed changes in response to a disruption or trigger.* | Qualitative | Project |
| Hoonsopon & Puriwat (2019) [8] | Organizational agility | *The ability of a firm to address and respond to uncertainty.* | Quantitative | Firm |
| Jacobs et al. (2011) [46] | Manufacturing agility | *The ability to positively respond to customers in real time.* | Quantitative | Firm |
| Kester et al. (2011) [5] | Agility | *The firm readily changes the composition of its NPD portfolio to reflect potential opportunities and threats.* | Qualitative | Firm |
| Kester et al. (2014) [7] | Agility | *The firm is agile in how it makes and implements NPD portfolio decisions.* | Quantitative | Firm |
| Kock & Gemünden (2016) [6] | Agility | *The ability to quickly adapt the firm's innovation portfolio to changing customer needs and competitive conditions, changing resource situations, changing technological opportunities and threats, and changing strategic goals.* | Quantitative | Firm |
| Lee & Xia (2010) [13] | Software Development Agility | *The software team's capability to efficiently and effectively respond to and incorporate user requirement changes during the project life cycle.* | Quantitative | Project |
| Lowry & Wilson (2016) [93] | IT agility (information, strategic, system agility) | *The ability to respond operationally and strategically to changes in the external environment through IT.* | Quantitative | Firm |
| Lu & Ramamurthy (2011) [33] | Organizational agility (market capitalizing, operational adjustment agility) | *A firm-wide capability to deal with changes that often arise unexpectedly in business environments via rapid and innovative responses that exploit changes as opportunities to grow and prosper.* | Quantitative | Firm |
| Sambamurthy et al. (2003) [94] | Agility (customer, partnering, operational agility) | *The ability to detect opportunities for innovation and seize those competitive market opportunities by assembling requisite assets, knowledge, and relationships with speed and surprise.* | Conceptual | Firm |
| Swafford et al. (2006) [95] | Supply chain agility | *The supply chain's capability to adapt or respond in a speedy manner to a changing marketplace environment.* | Quantitative | Firm |
| Tallon & Pinsonneault [96] | Agility | *The ability to detect and respond to opportunities and threats with ease, speed, and dexterity.* | Quantitative | Firm |
| Wang et al. (2014) [97] | Enterprise agility | *The ability to sense changes in the environment and respond in a timely, cost-effective manner.* | Qualitative | Firm |
| Zhu & Gao (2021) [98] | Supply chain agility | *The firm's ability to sense and respond to environmental changes in a timely manner.* | Quantitative | Firm |

## TABLE 2. Overview of Studies Discussing Agility from a Capability Perspective

| Study | Theoretical construct(s) (Dimensions) | Definition | Type of Study | Unit of analysis |
|---|---|---|---|---|
| Bianchi et al. (2020) [14] | Agile-Sprints/Agile-Feedback/ Agile-Specification | *The developers' use of iterative, time-boxed, well-defined work cycles for the development of appropriately sized items/The early and frequent deployment of beta tests and flexible adaptation to it/The gradual, delayed requirements detailing, and dynamic scoping.* | Quantitative | Firm |
| Cooper & Sommer (2016) [10] | Agile | *A project management method that brings agility, adaptability, and speed to development projects.* | Qualitative | Firm |
| Dabić et al. (2021) [20] | Intellectual agility | *Individuals' learning about the challenges faced by organizations and subsequently putting this learned knowledge into practice within an organization, refining the company's stock of knowledge and skills in line with the requirements of its changing environment.* | Quantitative | Firm |
| Doz & Kosonen (2010) [50] | Strategic agility (strategic sensitivity, leadership unity, resource fluidity) | *The thoughtful and purposive interplay on the part of top management between three 'meta-capabilities': Strategic sensitivity, leadership unity, resource fluidity.* | Conceptual | Firm |
| Gonzalez (2014) [35] | Agile project management | *A flexible organizational system for managing projects that involve the creation and the innovation of intellectual property (e.g., computer software, copyrightable material capturing concepts, and patents for inventions).* | Conceptual | Project |
| Gunasekaran (1998) [38] | Agile manufacturing (quick response manufacturing, global manufacturing, customized production, improved productivity & quality) | *The capability to survive and prosper in a competitive environment of continuous and unpredictable change by reacting quickly and effectively to changing markets, driven by customer-designed products and services.* | Conceptual | Firm |
| Kaufmann et al. (2020) [12] | Agile capabilities | *A project portfolio organization's intensity of and competence in applying agile practices.* | Quantitative | Firm |
| Lee & Xia (2010) [13] | Team Autonomy/Team Diversity | *The extent to which the software team is empowered with the authority and control in making decisions to carry out the project/The extent to which team members are different in terms of their functional backgrounds, skills, expertise, and work experience.* | Quantitative | Project |
| Maruping et al. (2009) [51] | Agile Methodology Use | *The use of agile practices in software development teams.* | Quantitative | Project |
| Mishra et al. (2017) [16] | Agile Project Management | *The extent to which project practices focused on improving project management agility were pursued in a project.* | Quantitative | Project |
| Recker et al. (2017) [52] | Agile management practices/ Agile development practices/ Agile standards and norms | *Rules and procedures, which prescribe behaviors and processes that must be followed/ Guidelines for individuals to focus on software testing, simplifying code, or enhancing code quality through peer review/Stipulation of acceptable team behaviors by sharing development standards and norms of artifacts and components (code).* | Quantitative | Project |
| Teece et al. (2016) [28] | Organizational agility (value protecting, value capturing activities) | *The capacity of an organization to efficiently and effectively redeploy/redirect its resources to value creating and value protecting (and capturing) higher-yield activities as internal and external circumstances warrant.* | Conceptual | Firm |
| Vijayasarathy & Turk (2012) [15] | Agile Use | *The extent to which specific agile development methods and techniques (e.g., XP, AUP, pair programming) are used.* | Quantitative | Individual |
| Present study | Agile R&D units' organization (culture, customer integration, autonomy, iterative work method, cross-functional capabilities, flat hierarchies) | *An R&D unit's organizational capability that combines cultural, structural, and process-based resources to increase the unit's adaptiveness to changing environments.* | Quantitative | R&D Unit |

**TABLE 3. Results of Exploratory Factor Analysis**

| **Dimensions**/Items | Item Code | CU | AU | CI | FH | CC | IW |
|---|---|---|---|---|---|---|---|
| **Culture** (α = .82; ω = .83) | | | | | | | |
| Please estimate how strongly the following values are shared in your unit. | | | | | | | |
| Courage to take self-responsibility and self-organization. | CU1 | **.54** | .26 | .14 | -.04 | .11 | -.17 |
| Commitment to achieving the agreed tasks and goals. | CU2 | **.54** | -.15 | .12 | .25 | .19 | -.02 |
| Respect between employees. | CU3 | **.82** | -.16 | -.01 | .12 | -.07 | .09 |
| *Openness regarding tasks, priorities, and project status.* | CU4 | -- | -- | -- | -- | -- | -- |
| *Focus on the currently agreed tasks and goals.* | CU5 | -- | -- | -- | -- | -- | -- |
| Mistakes are not seen as failures, but rather as learning opportunities. | CU6 | **.85** | .14 | -.05 | -.12 | -.01 | -.05 |
| Mistakes are dealt with openly. | CU7 | **.87** | .11 | -.11 | -.12 | -.07 | .04 |
| **Customer Integration** (α = .90; ω = .91) | | | | | | | |
| During the development of new products and services in my unit … | | | | | | | |
| … we involve customers in all development stages. | CI1 | .03 | .00 | **.93** | .01 | .01 | -.06 |
| … we co-design products and services with our customers. | CI2 | -.05 | .01 | **.94** | -.05 | -.05 | .01 |
| … we often gather customers' opinions on prototypes. | CI3 | -.06 | -.02 | **.86** | .03 | .01 | .13 |
| … *customers join our product development team temporarily, e.g., to test new products and services.* | CI4 | -- | -- | -- | -- | -- | -- |
| **Autonomy** (α = .77; ω = .79) | | | | | | | |
| In my unit, employees … | | | | | | | |
| … are strongly encouraged to make their own decisions. | AU1 | .19 | **.72** | .04 | .14 | -.12 | -.05 |
| … have the opportunity to select different ways to do their tasks. | AU2 | -.01 | **.84** | .02 | -.01 | .01 | .08 |
| ... make their own decisions without detailed management influence. | AU3 | -.04 | **.78** | -.06 | .05 | .05 | .02 |
| *... determine how tasks are done as a team.* | AU4 | -- | -- | -- | -- | -- | -- |
| **Iterative Work-method** (α = .77; ω = .78) | | | | | | | |
| In my unit … | | | | | | | |
| … we regularly present working interim results (e.g., prototypes, minimum viable products, ...). | IW1 | .05 | -.08 | .03 | -.07 | .02 | **.83** |
| … the workflows are characterized by iterative planning and execution cycles. | IW2 | -.04 | .05 | -.00 | -.04 | .01 | **.86** |
| … the completed work cycle is reflected, and findings are derived from it. | IW3 | .02 | .14 | .07 | .05 | -.01 | **.72** |
| *... goals are continuously adjusted during the course of the project based on gained knowledge.* | IW4 | -- | -- | -- | -- | -- | -- |
| **Cross-functional Capabilities** (α = .72; ω = .77) | | | | | | | |
| In my unit … | | | | | | | |
| … the employees can support each other professionally and compensate another in case of failures. | CC1 | -.08 | -.12 | -.09 | .07 | **.89** | -.02 |
| … the employees are able to get familiar with related areas and taking over tasks. | CC2 | -.03 | .05 | .05 | -.04 | **.87** | .03 |
| … the employees are able to understand the tasks of the areas outside their field of expertise (e.g., purchasing, controlling, sales, etc.). | CC3 | .10 | .14 | .01 | -.08 | **.63** | .03 |
| *... the employees have a wide range of specialist knowledge, as well as profound expert knowledge (T-shape).* | CC4 | -- | -- | -- | -- | -- | -- |

**TABLE 3. Continued**

| **Dimensions**/Items | Item Code | CU | AU | CI | FH | CC | IW |
|---|---|---|---|---|---|---|---|
| **Flat Hierarchies** (α = .75; ω = .75) | | | | | | | |
| My unit is characterized by flat structures and short information paths. | FH1 | -.13 | .01 | .05 | **.93** | -.03 | -.14 |
| In my unit, decisions are made on a professionally appropriate hierarchical level. | FH2 | -.05 | .27 | -.06 | **.76** | .05 | .03 |
| In my unit, the communication is open, i.e., we share information and appreciate discussions and different opinions. | FH3 | .27 | -.09 | -.05 | **.62** | -.04 | .17 |
| *In my unit, there are limited opportunities to continue working until the supervisor has approved a decision.* | FH4 | -- | -- | -- | -- | -- | -- |

Principle-component factor analysis with Promax rotation; items in italic are not part of the purified measurement; Eigenvalues > 1 were considered; n = 175; α = Cronbach's alpha; ω = McDonald's omega; factors are labelled as follows: CU = Culture, CI = Customer Integration, AU = Autonomy, IW = Iterative Work-method, CC = Cross-functional Capabilities, FH = Flat Hierarchies.

**TABLE 4. Results of Confirmatory Factor Analysis**

| | **R&D Employees Sample** | | | | | **R&D Managers Sample** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Dimension/Item Code | λ/Stand. Loading | α | ω | CR | AVE | λ/Stand. Loading | α | ω | CR | AVE |
| **Culture** | .85 | .87 | .87 | .86 | .55 | .83 | .82 | .83 | .83 | .50 |
| CU1 | .77 | | | | | .64 | | | | |
| CU2 | .74 | | | | | .62 | | | | |
| CU3 | .69 | | | | | .69 | | | | |
| CU6 | .77 | | | | | .79 | | | | |
| CU7 | .74 | | | | | .77 | | | | |
| **Customer Integration** | .40 | .93 | .93 | .93 | .81 | .32 | .90 | .91 | .90 | .75 |
| CI1 | .91 | | | | | .88 | | | | |
| CI2 | .95 | | | | | .87 | | | | |
| CI3 | .83 | | | | | .85 | | | | |
| **Autonomy** | .78 | .86 | .85 | .86 | .67 | .80 | .77 | .79 | .79 | .55 |
| AU1 | .83 | | | | | .80 | | | | |
| AU2 | .85 | | | | | .80 | | | | |
| AU3 | .78 | | | | | .62 | | | | |
| **Iterative Work-method** | .79 | .82 | .82 | .83 | .61 | .43 | .77 | .78 | .77 | .53 |
| IW1 | .73 | | | | | .68 | | | | |
| IW2 | .81 | | | | | .75 | | | | |
| IW3 | .80 | | | | | .75 | | | | |
| **Cross-functional Capabilities** | .63 | .76 | .78 | .78 | .54 | .48 | .72 | .77 | .76 | .52 |
| CC1 | .76 | | | | | .65 | | | | |
| CC2 | .82 | | | | | .90 | | | | |
| CC3 | .60 | | | | | .57 | | | | |
| **Flat Hierarchies** | .91 | .74 | .74 | .75 | .50 | .72 | .75 | .75 | .75 | .51 |
| FH1 | .64 | | | | | .63 | | | | |
| FH2 | .77 | | | | | .85 | | | | |
| FH3 | .70 | | | | | .64 | | | | |

Model fit R&D Employees Sample (n = 454); Comparative fit index [CFI] = .951; Root mean square error of approximation [RMSEA] = .058; Standardized root mean square residual [SRMR] = .051; Model fit R&D Managers Sample (n = 175); [CFI] = .935; [RMSEA] = .056; [SRMR] = .079; λ = second-order loading of ARDO dimension; α = Cronbach's alpha; ω = McDonald's omega; CR = composite reliability; AVE = average variance extracted

**TABLE 5. Correlations Among the ARDO Dimensions and Agility/Front-end Success (FES)**

| | Agility | FES |
|---|---|---|
| ARDO Measure | .50 | .52 |
| Culture | .44 | .41 |
| Customer Integration | .22 | .29 |
| Autonomy | .26 | .25 |
| Iterative Work-method | .30 | .40 |
| Cross-functional Capabilities | .34 | .34 |
| Flat Hierarchies | .40 | .31 |

n = 169, all correlations are significant at the 1% level.

## APPENDIX A. The final and validated ARDO scale

**Culture**

*Please estimate how strongly the following values are shared in your unit. (1 = not at all; 7 = to a large extent)*

Courage to take self-responsibility and self-organization.

Commitment to achieving the agreed tasks and goals.

Respect between employees.

Mistakes are not seen as failures, but rather as learning opportunities.

Mistakes are dealt with openly.

*Please evaluate to which degree the following statements apply to the situation within your unit. (1 = does not apply at all; 7 = applies completely)*

**Customer Integration**

During the development of new products and services in my unit …

… we involve customers in all development stages.

… we co-design products and services with our customers.

… we often gather customers' opinions on prototypes.

**Autonomy**

In my unit, employees …

… are strongly encouraged to make their own decisions.

… have the opportunity to select different ways to do their tasks.

... make their own decisions without detailed management influence.

**Iterative Work-method**

In my unit …

… we regularly present working interim results (e.g., prototypes, minimum viable products, ...).

… the workflows are characterized by iterative planning and execution cycles.

… the completed work cycle is reflected, and findings are derived from it.

**Cross-functional Capabilities**

In my unit …

… the employees can support each other professionally and compensate another in case of failures.

… the employees are able to get familiar with related areas and taking over tasks.

… the employees are able to understand the tasks of the areas outside their field of expertise (e.g., purchasing, controlling, sales, etc.).

**Flat Hierarchies**

My unit is characterized by flat structures and short information paths.

In my unit, decisions are made on a professionally appropriate hierarchical level.

In my unit, the communication is open, i.e., we share information and appreciate discussions and different opinions.